

A COMPLETE SOUTHERN SKY REDSHIFT SURVEY¹

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ABSTRACT

We discuss a magnitude-limited redshift survey covering a region around the south Galactic pole (SSRS2). The survey includes 3592 galaxies and covers a region of 1.13 sr to a limiting $m_{B(0)} = 15.5$, directly comparable to CfA2. Together, CfA2 and SSR2 cover more than a third of the sky.

The northern and southern surveys are remarkably similar. Both contain voids with diameters as large as 5000 km s⁻¹. The southern survey contains the Southern Wall, similar to the northern Great Wall. The distributions of velocity dispersions for systems extracted from the SSRS2 and CfA2 surveys are also remarkably similar.

For the SSRS2, an inhomogeneity-independent technique yields Schechter luminosity function parameters $M^* = -19.50$ and $\alpha = -1.20$ ($H_0 = 100 h$ km s⁻¹ Mpc⁻¹; $h = 1$ unless otherwise specified). The steep faint-end slope is probably attributable to bluer galaxies. By examining the normalized density fluctuations in the SSRS2 and CfA2 surveys, we suggest that the combined sample is not yet large enough to be “fair.” There are large fluctuations in shells at 10,000 km s⁻¹.

Subject headings: cosmology: observations — galaxies: clustering — galaxies: distances and redshifts — galaxies: luminosity function, mass function — large-scale structure of universe

1. INTRODUCTION

Redshift surveys with a range of sampling strategies have uncovered remarkable coherent structures in the distribution of galaxies on scales $\gtrsim 50 h^{-1}$ Mpc (Geller & Huchra 1989 [CfA2]; Broadhurst et al. 1990; Shectman et al. 1992; Giovanelli & Haynes 1993; Vettolani et al. 1993). Galaxy surveys now probe scales up to $\sim 200 h^{-1}$ Mpc. The ratio of power on scales $\gtrsim 50 h^{-1}$ Mpc to the power on smaller scales (Vogeley et al. 1992; Fisher et al. 1993) exceeds the predictions of the “standard” cold dark matter (CDM) model (Blumenthal et al. 1984). Although the power spectra for optically selected (Vogeley et al. 1992) and IRAS-selected (Fisher et al. 1993) samples agree except for an overall normalization, there are concerns that redshift surveys accomplished with different strategies in different regions of the sky may not “look” the same. Such concerns have often been expressed in comparing surveys of the northern and southern Galactic hemispheres.

The original southern survey (SSRS; da Costa et al. 1988) is diameter-limited, in contrast to the northern CfA magnitude-limited survey (Huchra et al. 1983). Here we discuss a new, deeper magnitude-limited southern survey (SSRS2) which includes 3592 galaxies. This survey covers a region of 1.13 sr

around the south Galactic pole to a limiting $m_{B(0)} = 15.5$ and is directly comparable to CfA2. We find, in fact, that the northern and southern surveys are remarkably similar. Taken together, CfA2 and SSRS2 cover more than a third of the sky. Over the north and south Galactic polar regions, we can compare these wide-angle shallow surveys with the nearest peaks in the pencil-beam survey by Broadhurst et al. (1990).

The power spectrum is only one of the quantitative measures important for discriminating among models for the formation of large-scale structure in the universe. Dense surveys completely covering a large solid angle (Huchra et al. 1983; da Costa et al. 1988; Geller & Huchra 1989) are particularly important for investigation of higher order statistics like the genus and the void probability function. We plan to report on these statistics soon.

Here we compute the luminosity function. The SSRS2 and CfA2 each cover enough volume to measure the luminosity function for magnitudes as faint as $M \simeq -14$. The behavior of the faint end of the luminosity function is important for the interpretation of deep counts (Koo & Kron 1992). We also examine fluctuations in the normalized density of the sample; these fluctuations reflect the large-scale features contained within these regions.

In § 2 we describe the sample and discuss the general characteristics of the galaxy distribution. In § 3 we estimate the luminosity function and the mean galaxy density. Section 4 is a summary.

2. DISTRIBUTION OF GALAXIES

2.1. The Sample

We constructed a sample of 3592 galaxies with $m_{B(0)} \leq 15.5$ from a combination of two machine-generated two-dimensional catalogs: the Automatic Plate Measuring (APM) Galaxy Survey (Maddox et al. 1990) and the nonstellar object list of the STScI Guide Star Catalog (GSC) (Lasker et al. 1990

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and references therein). In addition, we used the Surface Photometry Catalogue of the ESO-Uppsala Galaxies (Lauberts & Valentijn 1989) both to provide the original calibration of our magnitude system and to select bright galaxies not identified by the automatic procedures. For declinations north of $\delta = -17^\circ.5$ we used the Morphological Catalogue of Galaxies (Vorontsov-Velyaminov & Arkhipova 1963–1968, hereafter MCG) to select bright galaxies.

To construct the catalog from the GSC nonstellar object list, we first calibrated the relation between raw GSC magnitudes and $B(0)$ (Alonso et al. 1993, 1994). We then selected all objects with $B(0) \leq 15.5$. Objects in this list with matching entries in the ESO, MCG, or APM catalogs are galaxies in our sample. We examined objects without a match on the film copies of the ESO/SRC plates or POSS. In this way we added additional galaxies to the sample: approximately 10% of the objects in the final sample appeared only in the GSC.

Our sample covers the declination range $-40^\circ \leq \delta < -2^\circ.5$ with Galactic latitude $b \leq -40^\circ$; the solid angle subtended by the sample is 1.13 sr. This limit minimizes extinction problems. The sample we discuss here includes 3525 galaxies with measured redshifts. Eighteen of the remaining galaxies are either low surface brightness objects or galaxies with superposed stars for which we cannot obtain a redshift. In the declination range $-40^\circ \leq \delta < -10^\circ$, the sample is more than 99% complete to the magnitude limit. In the declination range $-10^\circ \leq \delta < -2^\circ.5$ we have redshifts for all but 49 galaxies ($\sim 93\%$ complete). About 60% of the radial velocities are new

measurements from CASLEO, CTIO, ESO, FLWO, and SAAO over the period 1988–1992.

2.2. Redshift Maps

Figure 1 shows the distribution of the 3269 galaxies with redshifts $\leq 15,000 \text{ km s}^{-1}$ in four slices at constant declination. The three complete slices are 10° thick; the northernmost $7^\circ.5$ slice is missing ~ 50 galaxies (see § 2.1).

Perhaps the most striking feature in the southern hemisphere is the Southern Wall (SW; see da Costa et al. 1988). This structure runs diagonally across the survey volume from $\alpha = 5^{\text{h}}$ and $cz = 5000 \text{ km s}^{-1}$ to about $\alpha = 0^{\text{h}}$ and $cz = 10,000 \text{ km s}^{-1}$. It is visible over the entire declination range, forming a two-dimensional thin sheet with an extent of at least $60 \times 100 \text{ h}^{-1} \text{ Mpc}$. This “wall” is the boundary of several voids. The largest and best-defined of these voids is centered at $\sim 23^{\text{h}}$, $v \sim 6000 \text{ km s}^{-1}$; it is most cleanly delineated in the $-40^\circ \leq \delta < -30^\circ$ slice and extends at least to -10° . A number of smaller voids are also apparent. The Telescopium-Pavo-Indus complex lies at the western edge of the survey volume ($\alpha \sim 21^{\text{h}}$).

The general nature of the large-scale distribution in our southern survey is similar to the northern Center for Astrophysics (CfA) survey. Figure 2 (Plate L1) shows all of the data from Figure 1 (*lower portion*) along with the CfA2 northern survey (*upper portion*). The CfA survey includes 6238 galaxies with redshifts less than $12,000 \text{ km s}^{-1}$ and covers the right ascension range $8^{\text{h}} \leq \alpha \leq 17^{\text{h}}$ and the declination range $8^\circ.5 \leq$

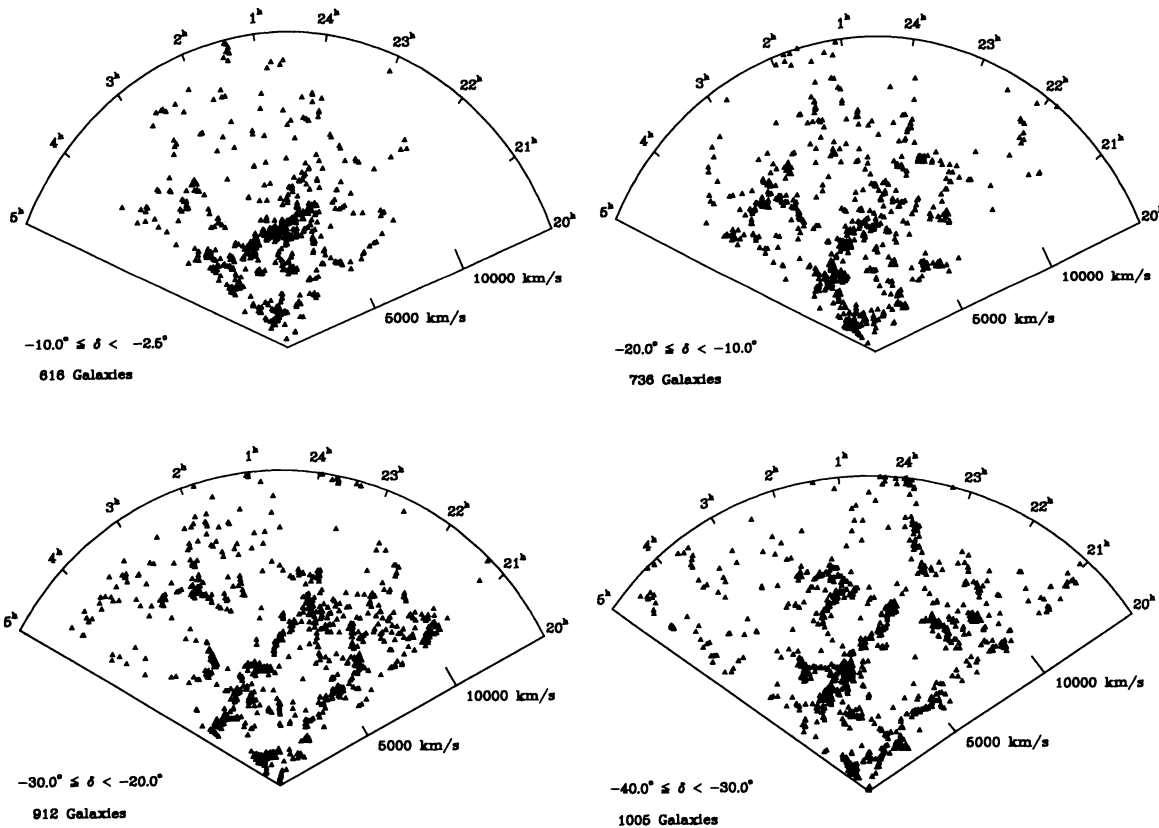


FIG. 1.—Right ascension vs. radial velocity for the SRS2 galaxies with $cz \leq 15,000 \text{ km s}^{-1}$ in four declination slices. The incomplete slice $-10^\circ \leq \delta < -2^\circ.5$ is $7^\circ.5$ wide. We display the complete region $-40^\circ \leq \delta < -10^\circ$ in three 10° slices.

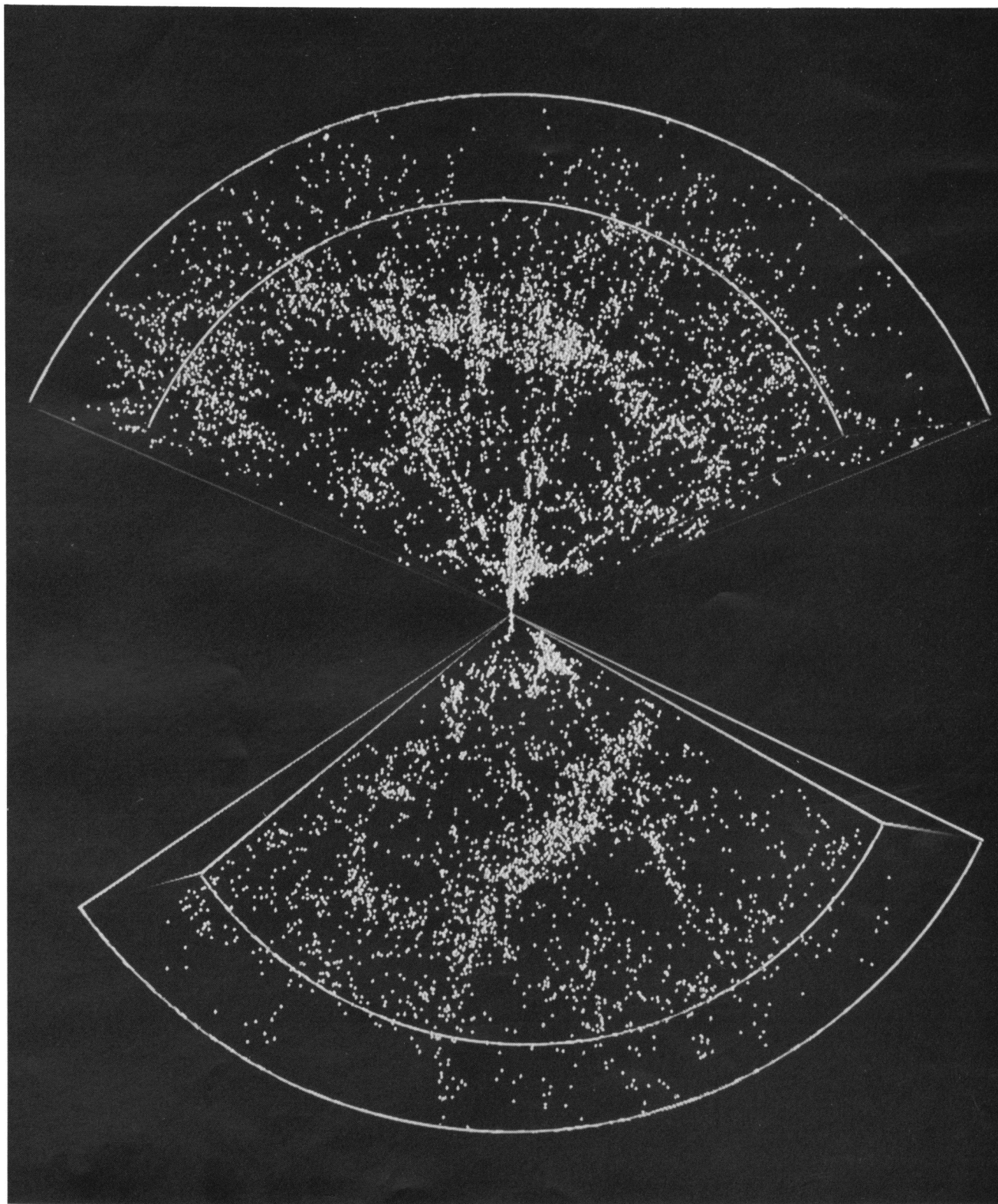


FIG. 2.—Display of CfA2 (north; *upper portion*) and SSRS2 (south; *lower portion*) for $cz \leq 12,000 \text{ km s}^{-1}$. For CfA2 the box shows the declination limits $8^{\circ}5' \leq \delta < 44^{\circ}5'$ and the right ascension limits $8^{\text{h}} \leq \alpha \leq 17^{\text{h}}$. The inner arc is $\delta = 44^{\circ}5'$. In the south the box limits are $-40^{\circ} \leq \delta < -2^{\circ}5'$ and the right ascension limits are $20^{\text{h}}8' \leq \alpha \leq 4^{\text{h}}$. The inner arc is $\delta = -2^{\circ}5'$. There are 9325 galaxies (*points*) in the image. (Graphics by E. E. Falco and M. J. Geller.)

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$\delta < 44^\circ$. The SSRS2 display includes 3087 galaxies with $cz \leq 12,000 \text{ km s}^{-1}$ and with declination $-40^\circ \leq \delta < -2^\circ$ and Galactic latitude $b \leq -40^\circ$.

Both the northern and southern surveys contain voids as large as $\sim 5000 \text{ km s}^{-1}$ in diameter bounded by extended thin structures. Several wall-like features similar to the Great Wall (GW; Geller & Huchra 1989), though perhaps not so extensive, lie within the southern survey volume. The GW, the SW, and the large voids bounded by them are the most striking features.

A comparison of systems of galaxies in the northern and southern surveys yields a somewhat more quantitative measure of their similarity. Application of an objective group finding algorithm to a portion of the CfA survey (Ramella, Geller, & Huchra 1989) shows that Abell $R \geq 1$ clusters (Abell 1958) with velocities less than $12,000 \text{ km s}^{-1}$ are identifiable. In the portion of the CfA survey in Figure 3, there are 10 $R \geq 1$ Abell clusters within this range; in the southern survey (the survey volume is $\sim 15\%$ smaller than the northern survey volume) there are four Abell-Corwin-Olowin (ACO) rich clusters (Abell, Corwin, & Olowin 1989). Because clusters are clustered, this $\sim 2 \sigma$ difference is not significant. Running the group finding algorithm on the southern data yields a further measure: the median velocity dispersion of the 173 groups in the region is 180 km s^{-1} , comparable to the 209 km s^{-1} obtained by Ramella et al. for a portion of the northern survey.

It is also interesting to compare our southern survey with the deeper, narrow beam surveyed by Peterson et al. (1986). Their survey (S1) is centered at $\alpha = 0^{\text{h}}56^{\text{m}}51^{\text{s}}$ and $\delta = -28^\circ 3'$ and covers 14.1 square degrees to a limiting $b_j = 17$. Six of the galaxies in our survey are included in S1; of these, five have redshifts between 5361 and 5706 km s^{-1} (in the SW), and the sixth has a velocity of $12,110 \text{ km s}^{-1}$. The S1 galaxies, which are as much as 2 mag fainter than galaxies in our survey, trace the same structures as our southern survey galaxies. In particular, nine (four of these are fainter than our limit) S1 galaxies lie in the SW and none fall into the voids on either side of it.

The S1 survey is the shallow portion of the even deeper southern probe of Broadhurst et al. (1990). Their surveys toward the north and south Galactic poles (i.e., vertically through the display in Fig. 2) suggest that the narrow peaks

which appear in their redshift distribution are structures similar to the Great Wall. Figure 2 and their Figure 1 show that the two nearest peaks in their survey are the GW and the SW. The situation at larger redshift remains debatable because our samples are too sparse at redshifts $\gtrsim 10,000 \text{ km s}^{-1}$.

3. LUMINOSITY FUNCTION AND MEAN DENSITY

The luminosity function is fundamental to the analysis of any redshift survey. Because of the obvious large-scale structure in the survey, we use an inhomogeneity-independent technique (Sandage, Tammann, & Yahil 1979, hereafter STY). We assume that the luminosity function is independent of position. We first fit a Schechter function using the STY technique. We then apply the stepwise maximum-likelihood (SWML) technique (Efstathiou, Ellis, & Peterson 1988) to evaluate the goodness of fit.

We compute the luminosity function for the complete region of the survey with $-40^\circ \leq \delta < -10^\circ$ (2919 galaxies). We correct the data to the Local Group frame using $v = v_\odot + 300 \sin l \cos b$; we infer distances directly from the corrected redshifts. Because morphological types for galaxies in our sample are unknown, we apply the generic K -correction, $3z$ (Pence 1976). We correct for Malmquist bias assuming that the dispersion in the magnitudes is $\sigma_m = 0.35$.

Figure 3 shows the luminosity function. We display both the SWML estimates and the STY fit. The Schechter function fitted to these data is sensitive to departures at the bright end ($M \leq -21.5$). The fit to the entire range ($-22 < M < -14$) yields $M^* = -19.50$ and $\alpha = -1.20$. The likelihood-ratio test shows that the data are consistent with a Schechter function.

The SSRS2 and CfA2 (Marzke, Huchra, & Geller 1994c) luminosity functions are roughly consistent in form, but the values of M^* differ significantly possibly because of a difference in magnitude systems. The steeper slope here (in contrast, $\alpha_{\text{CfA2}} = -1.0$) corresponds to the faint-end excess in the CfA survey. The color information (Lauberts & Valentijn 1989) for this survey indicates that bluer galaxies dominate the faint end in this sample; irregular galaxies correspondingly dominate the faint end of the CfA2 luminosity function (Marzke, Geller, & Huchra 1994b; Marzke et al. 1994a). The overall consistency at the faint end is important for the interpretation of deep counts.

Our value of M^* agrees with the value -19.5 obtained by Loveday et al. (1992) for a deeper sample in the same region. The APM magnitude system (b_j) is consistent with the SSRS2 magnitudes, with a relative zero-point offset $\lesssim 0.2$ mag (Alonso et al. 1994). The normalization of the SSRS2 luminosity function, $\phi^* = 0.015 \pm 0.003 \text{ galaxies Mpc}^{-3}$, is also in good agreement with Loveday et al. (1992). Their value of $\alpha = -0.97$ is shallower than ours; the source of this $\sim 2 \sigma$ discrepancy is unclear (but see Marzke et al. 1994b).

Estimates of $N(v)/N_{\text{exp}}(v)$ as a function of depth provide another method of comparing the southern and CfA surveys. Here $N(v)$ is the number of galaxies observed in a 1000 km s^{-1} bin centered on velocity v ; $N_{\text{exp}}(v)$ is the number expected for a uniform distribution with the luminosity function individually determined for the CfA2 and SSRS2 samples. This measure is particularly robust because the fluctuations within each portion of the survey are normalized internally. In other words, the comparison is independent of the problems in comparing the magnitude systems.

Figure 4 shows the normalized density fluctuations for the SSRS2 (filled circles) and CfA2 surveys (open squares). It is

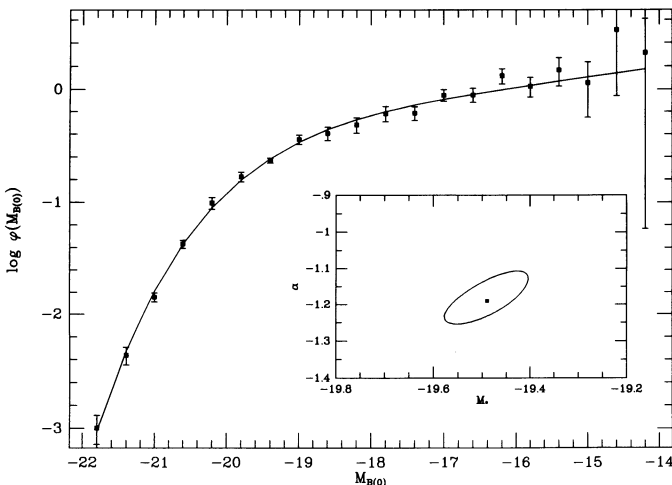


FIG. 3.—Luminosity function for the SSRS2. We show the SWML estimates of the luminosity function along with 1σ error bars. The curve is the STY Schechter function fit. The inset shows the 1σ confidence contour for M^* and α .

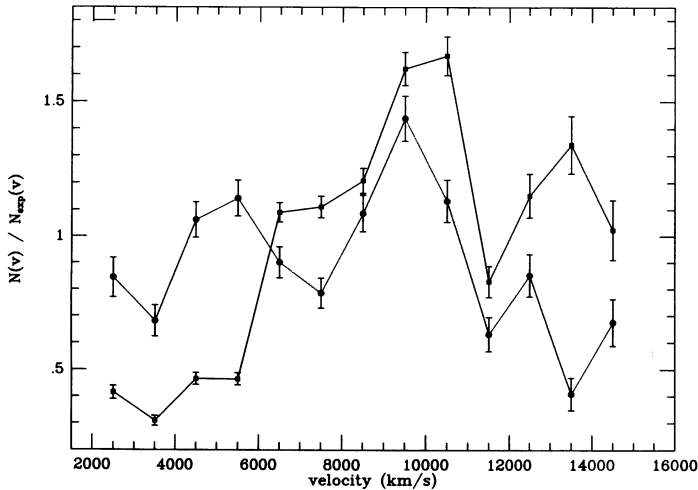


FIG. 4.—Variation of the normalized luminosity function amplitude. The SSRS2 (filled circles) and CfA2 (open squares) are normalized to N_{exp} , the number of randomly distributed galaxies appropriate for the particular sample. Error bars are 1σ Poisson errors.

striking that the fluctuations in the south are typically smaller by about a factor of 2. The peak in the north at $\sim 10,000$ km s^{-1} is so apparent because the GW is largely perpendicular to the line of sight. The analogous SW does not produce as large a signal because it runs diagonally across the survey and is thus averaged over the volume of several shells. However, there is a significant fluctuation in the south at $10,000$ km s^{-1} probably reflecting the structure visible in Figure 2. In the absence of large-scale coherence (e.g., features like the Great Wall), one would expect the amplitude of these fluctuations to decrease as we increase the volume of the shell. The sensitivity to features at $10,000$ km s^{-1} indicates that the sample is not yet extensive enough to be “fair.” At larger velocities the samples are too sparse for a meaningful comparison.

4. SUMMARY

The SSRS2 is a magnitude-limited redshift survey covering a region around the south Galactic pole. The survey includes 3592 galaxies and covers a region of 1.13 sr to a limiting $m_{B(0)} = 15.5$, directly comparable to CfA2. Taken together CfA2 and SSRS2 cover more than a third of the sky.

The northern and southern surveys are remarkably similar. Both contain voids with diameters as large as 5000 km s^{-1} . The southern survey contains the Southern Wall, similar to the northern Great Wall. These two features are responsible for the nearest two sharp peaks in the narrow, deep probes of Broadhurst et al. (1990). A southern probe (Peterson et al. 1986), which contains galaxies up to 2 mag fainter than our limit, adds no galaxies to the sharply defined nearby voids in the wide-angle survey.

The distribution of velocity dispersions for systems extracted from the SSRS2 and CfA2 surveys is also remarkably similar. Although at first glance the SSRS2 may appear to be deficient in rich clusters, the difference is at the $\lesssim 2\sigma$ level.

For the SSRS2, the STY technique yields luminosity function parameters $M^* = -19.50$ and $\alpha = -1.20$. The steeper α for SSRS2 (compared with CfA2) is probably attributable to bluer galaxies. In CfA2 there is a “faint-end excess” over the extrapolation of the best-fit Schechter function; we attribute this excess to blue irregulars (Marzke et al. 1994b).

By examining the normalized density fluctuations in the SSRS2 and CfA2 samples covering the north and south Galactic polar regions, we suggest that the combined sample is not yet large enough to be “fair.” The GW and the SW produce large fluctuations in shells at $10,000$ km s^{-1} . If we averaged appropriately over much such features, their effect would be averaged out over the largest shells. These fluctuations may be related to the flows observed by Lauer & Postman (1994). They argue that these flows are generated by inhomogeneities on a scale $\gtrsim 10,000$ km s^{-1} .

Dense, wide-angle surveys like the SSRS2 and CfA2 may be used as independent realizations to estimate the sampling variation for different statistical measures. When combined, these samples increase the contiguous volume for topological analyses; they decrease the error in the large-scale determination of the power spectrum.

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